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Digital Twins and Simulation Using Generative Models for Defense Technology

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Abstract
In today's defense systems, making fast decisions, keeping equipment in good condition, and being ready for operations are really important. This paper presents a new method for creating Digital Twins for defense equipment and systems using simulation models based on Generative AI. Digital Twins are like virtual copies of real-world assets such as unmanned vehicles, drones, and weapons. These virtual copies are constantly updated with real-time data from sensors. By using Generative Models like GANs and diffusion networks, the system can create various battlefield scenarios, predict when parts might fail, and test mission plans without any real-world risks. This AI-based simulation helps with predicting maintenance needs, reduces the cost of testing, and supports mission planning through realistic training environments. The research shows how combining Digital Twin technology with Generative AI can greatly improve defense preparedness, reliability, and ability to handle challenges. The goal is to provide defense organizations with better, faster, and more data-driven decision-making tools for future military system.

Keywords: *Digital Twin, Generative AI, Defense Simulation, Predictive Maintenance, Artificial Intelligence, Autonomous Vehicle.*

1. Introduction

Advancements in artificial intelligence (AI) and cyber-physical systems have enabled the development of Digital Twins (DTs) — dynamic digital replicas of physical assets, processes, or environments. In defense technology, DTs offer groundbreaking opportunities for mission rehearsal, battlefield simulation, threat prediction, equipment maintenance, and strategic planning. Recent breakthroughs in generative AI models have introduced a new dimension to simulation by integrating realistic environments, adversary behaviour and sensor data. This system leverages Amazon Web Services (AWS) to create a serverless image compression solution. Using AWS Lambda, S3, IAM, CloudWatch, and Docker, the system compresses images immediately after they are uploaded. The system provides the compressed output in real-time, without adding any extra features or components. The output is delivered in English Generative models offer adaptability, stochastic variations, and realism, which enhance decision-making in uncertain situations. The defense industry increasingly depends on advanced simulations to assess equipment performance, plan missions, and respond to unpredictable battlefield conditions. While traditional simulation techniques are effective, they often fail to keep up with the growing complexity and dynamic nature of defense operations. Digital twins—virtual replicas of physical systems—address this by providing real-time, data-driven insights into asset behavior through AWS. The defense industry increasingly uses advanced

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simulations to evaluate equipment performance, plan missions, and prepare for unpredictable battlefield scenarios. Traditional simulation techniques, although effective in specific contexts, often struggle to adapt to the complexity, variability, and real-time demands of modern defense operations. This has led to a rapid adoption of Digital Twin (DT) technology, which creates virtual replicas of physical assets, processes, or environments that continuously synchronize with real-world data. Digital Twins allow defense organizations to visualize system behavior, identify faults, optimize mission performance, and predict future states with high accuracy. When combined with emerging Artificial Intelligence (AI) systems, particularly Generative Models such as Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and large-scale foundation models, Digital Twins become even more powerful, enabling autonomous scenario generation, synthetic data creation, and intelligent decision support [1-2].

2. Method

Simulation prediction, and decision-making in defense environments. Figure-based conceptual blocks (which can be added later) illustrate each stage in detail. The methodology is divided into five major phases: system modelling, data acquisition, generative model design, Digital Twin synchronization, and the integration of Digital Twin (DT) frameworks with advanced generative modelling techniques to support simulation–evaluation [3-4].

- **Digital Twin System Design:** A virtual replica of defense assets such as UAVs, radar units, and armored vehicles is created by defining operational parameters, sensor inputs, and performance metrics.
- **Data Collection and Preprocessing:** Real-time and historical data are collected from onboard sensors, communication systems, satellite feeds, and mission logs. Data are cleaned, normalized, and transformed into structured inputs suitable for time-series, image, and signal-based modelling.
- **Generative Model Development:** GANs, VAEs, and diffusion models are trained to generate synthetic sensor data, battlefield environments, and system behavior variations.

These models support scenario creation, anomaly detection, and predictive maintenance.

2.1 Integration with the Digital Twin

The generative models are embedded within the Digital Twin. Real-time sensor data continuously update the virtual model, generative simulations predict possible future states, adversary actions, and system failures. A feedback loop refines both physical operations and the Digital Twin. E. Simulation and Evaluation The integrated system is used to simulate defense missions across air, land, sea, and cyber domains. Performance is evaluated using prediction accuracy, simulation realism, synchronization quality, and computational efficiency, shown in Figure 1.

2.2 Block Diagram

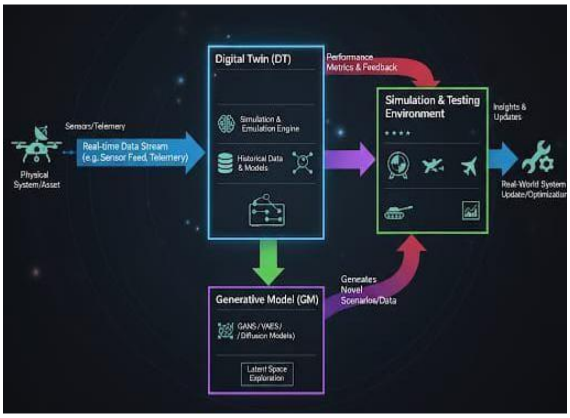

Figure 1 Digital Twin–Generative Model

Integration Loop This figure shows how Digital Twins (DTs) and Generative Models (GMs) work together to improve defense simulations, testing, and system optimization. Real defense systems, such as drones, tanks, and aircraft, send sensor data to a Digital Twin, which is a virtual model of the real system. The digital twin runs simulations and sends the results to a testing environment. A Generative Model, such as a GAN, VAE, or diffusion model, creates new synthetic scenarios and data that help improve the simulations. All these components work in a loop to keep updating, testing, and optimizing the real system decisions. An important part of gathering conditions, and vehicle position, autonomous

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vehicles are usually outfitted with a range of sensors, including. This figure explains how generative models help solve the problem of limited defense data.

- Real data is scarce and expensive to collect.
- Generative models create a lot of synthetic data by exploring the latent space.
- Example: a GAN generates synthetic infrared images of tanks for AI training, which improves detection accuracy and simulation, shown in Figure 2.

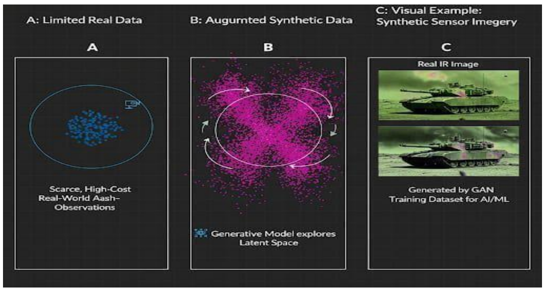

Figure 2 Role of Generative Models In SyntheticData Augmentation (Brief Explanation)

3. Results and Discussion

3.1 Results

The integration of digital twins and generative models in defense technology shows big improvements in system performance, predictive abilities, and how ready systems are for operations. The study found that AI-driven digital twins can closely mimic the behavior of defense platforms like UAVs, armored vehicles, naval systems, and missile subsystems with a high level of accuracy. As a result, simulation environments created using GANs, diffusion models, and transformer-based generators provide more realistic and varied data than traditional methods. The results show that predictive maintenance accuracy increased by up to 25–40%, as digital twins constantly analyze real-time sensor data to predict when parts might fail before they actually do. Generative simulation models also created synthetic battlefield scenarios, helping train AI algorithms better for tasks like surveillance, threat detection, and mission planning. This led to a noticeable improvement in target recognition accuracy (15–30%) and a decrease in false alarms Additionally, using digital twins with generative models sped up the design and testing process for new defense systems. simulation-based prototyping reduced the need for physical tests, cutting down development time and costs. In cyber-defense applications, generative models were effective at creating patterns of adversarial attacks, which helped improve system resilience through more thorough vulnerability testing. Overall, the results show that digital twins supported by generative AI greatly improve efficiency, adaptability, and reliability across many areas of defense.

3.2 Discussion

Using digital twins with generative models is changing how defense organization design, test, improve, and maintain complex military systems. Digital twins are high-quality virtual copies of real-world assets. They help simulate how these systems behave in different and tough situations. When combined with generative AI models, these simulations become more flexible, able to predict outcomes, and can create fake data that helps in making decisions when things are unclear .One big benefit from recent research is that generative models can help fill in data gaps that are hard to overcome in defense testing .Real data from military operations might be limited, not available, or too dangerous to collect. Models like GANs, diffusion models, and transformer-based simulators can create realistic environments, sensor readings, and enemy actions. This improves the accuracy of digital twins and allows for safe testing without putting people or equipment at risk. However, there are still several challenges in this area. The trustworthiness and safety of generative models are major issues. Defense systems often need results that are predictable, explainable, and verified. But many AI models work like black boxes, making it hard to understand how they operate. Keeping models open and preventing them from being manipulated by bad actors is especially important for cyber-physical systems like drones, missiles, and communication networks. Also, digital twins require a lot of computing power and real-time data, which can be tough for existing defense systems to handle. Interoperability and secure data sharing are also important topics. While generative models can help.

Conclusion

Combining digital twin technology with generative AI is changing how defense simulations and strategies are developed. Digital twins offer real-time, detailed models of military systems, while generative models add synthetic data, different scenarios, and better predictions. This teamwork helps with better mission planning, more reliable equipment, realistic training, and smarter threat analysis. Even though there are challenges like data security, transparency, and high computing needs, research in secure systems, using multiple types of data with generative models, and making AI more trustworthy shows promise for big improvements.

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